[2] Crapo L. Cushing's syndrome. A review of diagnostic tests. *Metabolism* 1979;**28**:955-77.
[3] Britton KE. Radionuclide imaging in adrenal disease. In: James VHT, ed. *The adrenal gland.* New York: Raven Press, 1979.
[4] Corrigan DF, Schaaf M, Whaley RA, Czerwinski CL, Earll JM. Selective venous sampling to differentiate ectopic ACTH secretion from pituitary Cushing's syndrome. *N Engl J Med* 1977;**296**:861-2.
[5] Reynes CJ, Churchill R, Moncada R, Love L. Computed tomography of adrenal glands. *Radiol Clin North Am* 1979;**17**:91-104.
[6] Korobkin M, White EA, Kressel HY, Moss AA, Montagne J-P. Computed tomography in the diagnosis of adrenal disease. *Am J Roentgenol* 1979; **132**:231-8.
[7] Dunnick NR, Schaner EG, Doppman JL, Strott CA, Gill JR, Javadpour N. Computed tomography in adrenal tumours. *Am J Roentgenol* 1979; **132**:43-6.
[8] Eghrari M, McLoughlin MJ, Rosen IE, *et al.* The role of computed tomography in assessment of tumoral pathology of the adrenal glands. *J Comput Assist Tomogr* 1980;**4**:71-7.
[9] Muhm JR, Brown LR, Crowe JK, Sheedy PF Hattery RR Stephens DH. Comparison of whole lung tomography and CT for detecting pulmonary nodules. *Am J Roentgenol* 1979;**131**:981-4.
[10] Sheedy PF II, Stephens DH, Hattery RR, MacCarty RL, Williamson B. Computed tomography of the pancreas. *Radiol Clin North Am* 1977; **15**:349-66.
[11] Allott EN, Skelton MO. Increased adrenocortical activity associated with malignant disease. *Lancet* 1960;ii:278-84.
[12] Besser GM, Edwards CRW. Cushing's syndrome. In: Mason AS, ed. *Clinics in endocrinology and metabolism.* Vol 1(13). London: W B Saunders, 1972:451-90.
[13] Montagne J, Kressel HY, Korobkin M, Moss AA. Computed tomography of the normal adrenal glands. *Am J Roentgenol* 1978;**130**:963-6.
[14] Karstaedt N, Sagel SS, Stanley RJ, Melson GL, Levitt RG. Computed tomography of the adrenal gland. *Radiology* 1978;**129**:723-30.
[15] Ryo UY, Johnston AS, Kim I, Pinsky SM. Adrenal scanning and uptake with ^{131}I-6/3-iodomethyl-nor-cholesterol. *Radiology* 1978;**128**:157-61.
[16] Sutton D. The radiological diagnosis of adrenal tumours. *Br J Radiol* 1975;**48**:237-58.
[17] Sample WF, Sarti DA. Computed tomography and gray scale ultrasonography of the adrenal gland: a comparative study. *Radiology* 1978; **128**:377-83.
[18] Symington T. *Functional pathology of the human adrenal gland.* Edinburgh and London: E and S Livingstone Ltd, 1969:120.

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Rebreathing in a subject wearing an integral crash helmet

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Abstract

The respired air of a volunteer was analysed while he was wearing a variety of integral crash helmets. Observations were made with and without a protective balaclava, bib or scarf, or both. Rebreathing occurred and the peak inspired oxygen tension fell as low as 16·0 kPa (120 mm Hg) with a minimum inspired carbon dioxide of 2·1 kPa (16·0 mm Hg).

Accessories worn or attached to the helmet which restrict airflow into the helmet should not be used. Attention should be paid to the "air conditioning" of helmets when worn with flameproof balaclavas and bibs.

Introduction

The value of protective headgear in reducing the incidence of head injuries in motorcycle and autosport racing accidents has been established.[1-3] The design of crash helmets was pioneered by neurosurgeons and other accident surgeons with head protection as the prime purpose. Schultz and Karlin in the USA have also argued the case for "full face" (integral) helmets.[4]

One of us (RD) observed that in a small number of motorcycle accidents a transient light-headedness or blackout may have preceded the accident and that in each of these cases, the victim was wearing an integral crash helmet with a scarf wrapped around his neck for protection against the cold. We therefore investigated the possibility that the wearing of integral crash helmets and accessories might lead to rebreathing.

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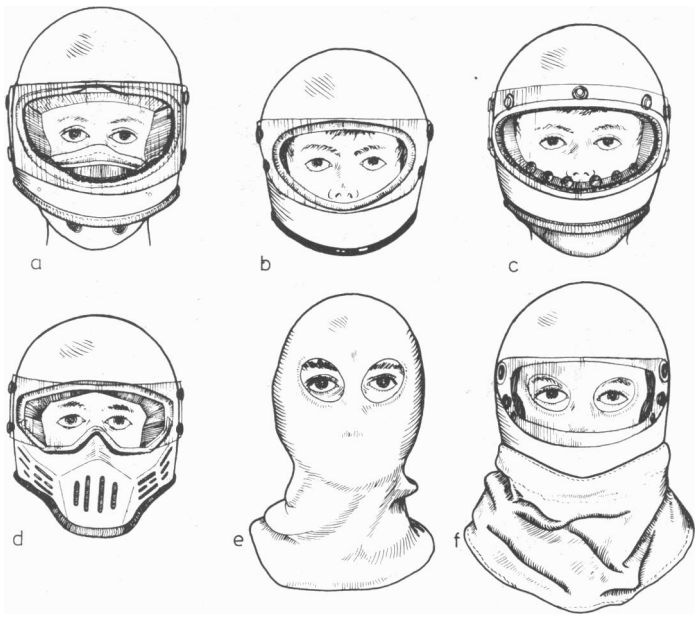
Methods

The features of the helmets tested and accessories are illustrated in fig 1. All the helmets were of integral design and some incorporated a vented visor or vents. The Stadium Achilles was unique in that it incorporated as an anti-misting device a "mouth cone" which resembled a full anaesthetic face mask (fig 1*a*). A motor racing driver may wear a flameproof balaclava and bib (*e* and *f*), and a motorcyclist



Helmets and accessories tested. (*a*) Achilles helmet made by Stadium Ltd, Caerphilly, Glamorgan (complies with BS 2495 integral design, incorporates anti-mist mask). (*b*) Bell Star made by Bell Helmets Inc, California (complies with BS 2495, no vents). (*c*) Jetstar JHP made by Griffin Helmets, Halesowen (complies with BS 2495, vented or non-vented visor). (*d*) RXM-1 made by Simpson Sports, Torrance, California (complies with Snell Foundation (USA) standard, flame filtration in nose piece). (*e*) Flameproof balaclava. (*f*) Bell Star helmet with protective balaclava and bib.

Mean (± SD) maximum inspired oxygen tensions and minimum inspired carbon dioxide tensions (kPa)

Helmet	Helmet alone		With scarf or bib			With balaclava and scarf or bib		
	Static	Fan	Static	Fan	Exercise	Static	Fan	Exercise
Stadium Achilles								
P_IO_2	17·4 (0·1)	17·3 (0·2)	16·9 (0·1)†	17·2 (0·2)	17·8 (0·3)§			
P_ICO_2	0·8 (0·1)	0·3 (0·1)*	1·0 (0·1)†	0·6 (0·2)	1·0 (0·3)			
Bell Star								
P_IO_2	18·0 (0·1)	19·2 (0·1)*				16·0 (0·2)†	17·3 (0·2)*	16·8 (0·3)‡
P_ICO_2	0·7 (0·1)	0·0*				2·1 (0·2)†	1·3 (0·2)*	1·4 (0·2)‡
Griffin Jetstar JHP (with vented visor)								
P_IO_2	16·9 (0·4)	19·4 (0·1)*	17·1 (0·3)	17·8 (0·3)*				
P_ICO_2	0·8 (0·2)	0·0*	1·3 (0·3)†	0·5 (0)*				
Griffin Jetstar JHP (non-vented visor)								
P_IO_2	17·0 (0·4)	19·4 (0·1)*	17·1 (0·3)	17·8 (0·3)*				
P_ICO_2	1·8 (0·1)	0·3 (0·1)*	1·7 (0·2)	0·8 (0·1)*				
Simpson RXM-1								
P_IO_2	16·9 (0·1)	19·2 (0·1)*				17·2 (0·2)†	18·2 (0·1)*	17·5 (0·1)‡
P_ICO_2	0·7 (0·1)	0·0*				1·3 (0·2)†	1·3 (0·2)*	1·4 (0·2)

Statistical significance $p = 0·001$ comparing *static with fan; †accessories with helmet only; ‡exercise with fan (with accessories); §exercise with fan (with scarf or bib).
Conversion: SI to traditional units—O_2 and CO_2: 1 kPa ≈ 7·5 mm Hg.

may improve his comfort and reduce draughts by wearing a knitted balaclava or head scarf around his neck. The helmets were tested incorporating these accessories.

Respiratory gases were analysed using a Medishield Multigas Medical Monitor MS2 with the tip of the analytical catheter fixed at the subject's nose in such a position to permit continuous breath-by-breath analysis of respired air. The instrument was calibrated using 5·6% carbon dioxide in nitrogen and room air and was accurate to ±0·2% oxygen (or carbon dioxide). The 90% response time of the whole system to a 5% step change in oxygen or carbon dioxide concentration was less than 100 ms. Repeat calibrations were done after each test. Tracings were taken of oxygen and carbon dioxide for alternating 30-second periods with the helmet visor up, and the results were recorded on a chart recorder. The visor was then closed and recordings were continued for three to five minutes after a stable state had been reached.

Each helmet was studied with and without the accessories appropriate for the particular helmet (balaclava, scarf, or bib) both in a static condition and with a fan providing an airflow over the helmet of 5 to 7·5 m/s (10-15 mph). Finally, tests were done on the subject during 10 minutes of exercise on a treadmill (speed 1·5 m/s with a 20° incline). The means (and standard deviations) were calculated from 10 peak (maximum) inspired oxygen tensions and 10 minimum carbon dioxide tensions. We then compared the differing conditions when the volunteer wore each helmet (see table).

Results

In normal use under static conditions (table) all helmets permitted some rebreathing. The P_IO_2 varied from 16·9 to 18·0 kPa (127-135 mm Hg) and the P_ICO_2 from 0·7 to 1·8 kPa (5·0 to 13·0 mm Hg). Tests using a fan showed that rebreathing was almost abolished, except with the Stadium Achilles. The addition of a scarf or bib significantly worsened rebreathing with the Stadium Achilles, but not with the Griffin Jetstar JHP (non-vented or vented). A fan produced a significant improvement in rebreathing except with the Stadium Achilles. When a balaclava, scarf, or bib was worn under static conditions there was a significant worsening of rebreathing with the Bell Star. Rebreathing lessened, however, with the Simpson RXM-1. Again the addition of the fan significantly lessened the rebreathing.

Exercise lessened rebreathing with all helmets compared with static values, probably due to deeper breathing and greater movement of gases in and around the helmet.

The Bell Star helmet (with balaclava and bib under static conditions) led to the lowest P_IO_2 (mean 16·0 kPa (120 mm Hg)) and highest P_ICO_2 (mean 2·1 kPa (16·0 mm Hg)) and was associated with a rise in ventilatory frequency to 26 per minute.

Discussion

The use of integral full-face crash helmets may lead to a rise in P_ICO_2 with a corresponding fall in P_IO_2. This is clear evidence of rebreathing. We are currently evaluating the effect of the rebreathing in subjects by measuring arterial oxygen and carbon dioxide tensions and ventilation. The airflow of 5 to 7 m/s that we used may not reflect airflow over a helmet. On the open road it may be greater, or the effective design of fairing, cowling, or streamlining may minimise or even eliminate this flow of air.

As only the peak inspired oxygen tensions were measured the results overestimate the true mean inspiratory oxygen tension. Interference with visual discrimination, night vision, and a worsening of performance on complex psychomotor tests occur with inspired oxygen concentrations between 16% and 18%.[5,6] Nevertheless, these effects have been seen at high altitude with subsequent hyperventilation, resulting in hypocapnia, and may not occur when hypercapnia is present. If these effects occur in riders or drivers wearing integral crash helmets there are extremely important implications for safety on the road and motor racing circuit.

Our results cannot be interpreted as condemning the use of crash helmets. The incidence of head injuries in Kansas rose by 70% when the law requiring compulsory wearing of helmets was repealed. The mortality in those not wearing crash helmets was increased threefold. The British Standards specifications for crash helmets[7,8] state protective aspects of helmets' design: there is no consideration of helmet ventilation. We would recommend that motorcyclists should not wear anything that restricts airflow into the helmet. If flameproof balaclavas and bibs are to be worn we would recommend a "vented" helmet to minimise rebreathing. Attention must be given to improving the "air conditioning" of integral helmets with accessories as worn by racing drivers.

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References

1 Dovley BJ, Trinca GW. In: Huelke DF, ed. *Proceedings of the American Association for Automotive Medicine 22nd conference.* Illinois: AAAM, 1978:49.
2 Whitaker J. *Motor cycle safety: accident survey and rider injuries, supplementary report 239.* Crowthorne: Transport and Road Research Laboratory, 1976.
3 Special Correspondent. Motorcycle and bicycle accidents. *Br Med J* 1979; i:39-41.
4 Schultz RC, Karlin JY. In: Huelke DF, ed. *Proceedings of the American Association for Automotive Medicine 22nd conference.* Illinois: AAAM, 1978:245.
5 Cotes JE. *Lung function.* 4th ed. Oxford: Blackwell, 1979:468.
6 Guyton AC. *Textbook of medical physiology.* Philadelphia: Saunders, 1979:588.
7 British Standards Institution. *BS5361.* London: BSI, 1976.
8 British Standards Institution. *BS2495.* London: BSI, 1977.